SANGUINE

ME215 Thermodynamics I
Final Exam: 2 May 2019

NAME

CWID

Make sure you find everything.

- Questions 1-19
- Crossword (make sure you add “Uniform Flow”)
- 3 Bonus problems

Notes

- You must include the direction of energy and mass flows when asked (eg, $\dot{w}_{out} = 3.7$ kW/kg, $Q_{in} = 14$ kJ, $\dot{m}_{out} = 3.7$ kg/s).
- You must carry units throughout your calculations. Mistakes that could’ve been identified by the resultant inconsistent units will be graded more harshly.
- You must show the equations you are using in your calculations. Do not expect anyone to figure it out from your values.
- Correct answers are not correct without you showing work to support them.

WRITE NEATLY. IF I CAN’T READ IT, IT’S NOT THERE.

SANGUINE

ME215-002/920/921: Thermodynamics I
Final Examination: 2 May 2019

Closed book. Closed notes. No formula sheet. All test materials needed are in this packet.
No Internet or communication allowed. Calculator is allowed.

190 points

Write your final answers on this problem sheet AND make sure your final answers are clearly identified in your work. Make sure you turn in ALL of your work sheets.

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1. _______________(5) Helium (P_1 = 2 MPa, T_1 = 600 K) is throttled to P_2 = 1.2 MPa. Assuming ideal gas behavior, which describes the downstream temperature T_2?

   (a) $T_2 < T_1$ (b) $T_2 = T_1$ (c) $T_2 > T_1$

2. _______________(5) A fluid is at its critical point. The temperature is lowered while the pressure is held constant. What is the phase of the fluid after the change?

3. _______________(5) A saturated liquid has its volume increased while temperature is held constant. What change in pressure accompanies the volume change?

A system consists of a saturated liquid/vapor mixture. Heat is added to the system at constant temperature.

4. _____(5) The quality
   (a) increases (b) decreases (c) stays the same (d) not enough information

5. _____(5) The temperature
   (a) increases (b) decreases (c) stays the same (d) not enough information

6. _____(5) The pressure
   (a) increases (b) decreases (c) stays the same (d) not enough information

7. (10) Provide two pertinent assumptions of the Ideal Gas Equation of State.

   ____

   ____

8. (10) A vessel contains 3 kg of H2O at 60 bar, 400 °C. Heat is lost from the vessel, causing the system to lose entropy, where $\Delta s_{sys} = -0.5$ kJ/kg-K. Does this violate the Increase in Entropy Principle? Explain.

WRITE NEATLY. IF I CAN'T READ IT, IT'S NOT THERE.

A heat engine receives heat from a source at 1500 K at a rate of 700 kJ/s and it rejects waste heat to a medium at 320 K. The measured power output of the heat engine is 320 kW. and the environment temperature is 25 °C. Determine

9. _______________ kW (10) the reversible power output,

10. _______________ (10) the first-law efficiency of this heat engine, and

11. _______________ (10) the second-law efficiency of this heat engine.

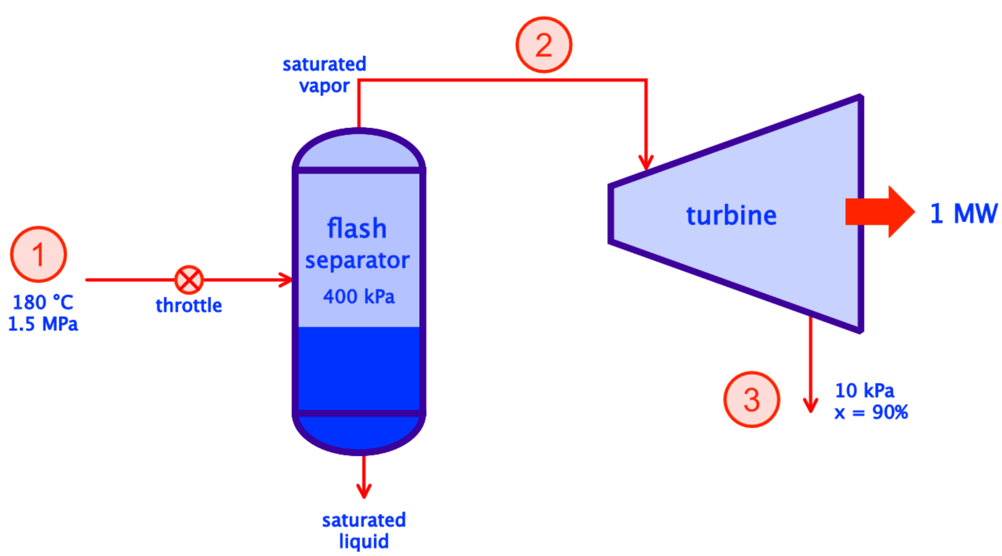
12. _______________°C (10) A sealed rigid vessel (volume = 3 m^3) contains 100 kg of propane. The tank bursts at 2 MPa. What is the maximum allowable temperature (to avoid bursting) [°C]?

13. _______________(10) Walking outdoors at -40 °C, you find a container of propane, also at -40 °C. You determine that the propane inside exists as both liquid and vapor. You decide to open the container. Does air flow in or does propane flow out? Why? Prove it.

A proposal is made to use a geothermal supply of hot water to operate a steam turbine, as shown below. The high-pressure water at 1.5 MPa, 180 °C is throttled into a flash evaporator chamber, which forms liquid and vapor at a lower pressure of 400 kPa. The liquid is discarded while the saturated vapor feeds the turbine and exits at 10 kPa, 90% quality. The turbine power output is 1.21 MW.

Assume: $v_1 = 0.0011270$ m^3/kg; $u_1 = 761.748$ kJ/kg; $h_1 = 763.439$ kJ/kg; $s_1 = 2.1389$ kJ/kg-K.

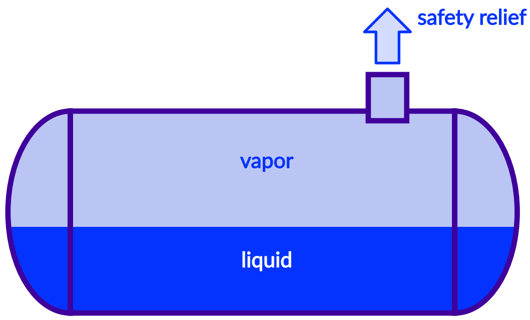
14. _______________kg/s (20) Find the required mass flow rate $(\dot{m}_1)$ of hot geothermal water.



A 2000-L tank initially contains water at 100 kPa and a quality of 10%. Heat is transferred to the water, thereby raising its pressure and temperature. At a pressure of 1 MPa, a safety valve opens and saturated vapor at 1 MPa flows out. The process continues, maintaining 1 MPa until the quality in the tank is 90%, then stops. Determine

15. _______________kg (10) Mass of water to exit

16. _______________kJ (10) Total heat transfer

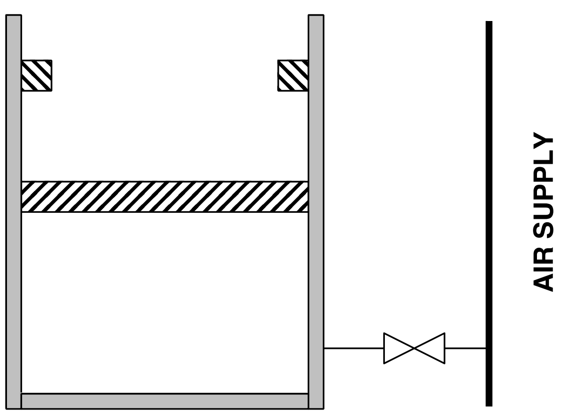


A piston/cylinder device with a freely floating piston contains air at 300 kPa, 17 °C and volume 0.25 m^3. The maximum volume of the enclosed chamber is 1 m^3, limited by stops that restrict piston motion. An air line (500 kPa, 600 K) is connected by a valve to the chamber. The valve is opened until the chamber conditions are 400 kPa, 350 K. Find

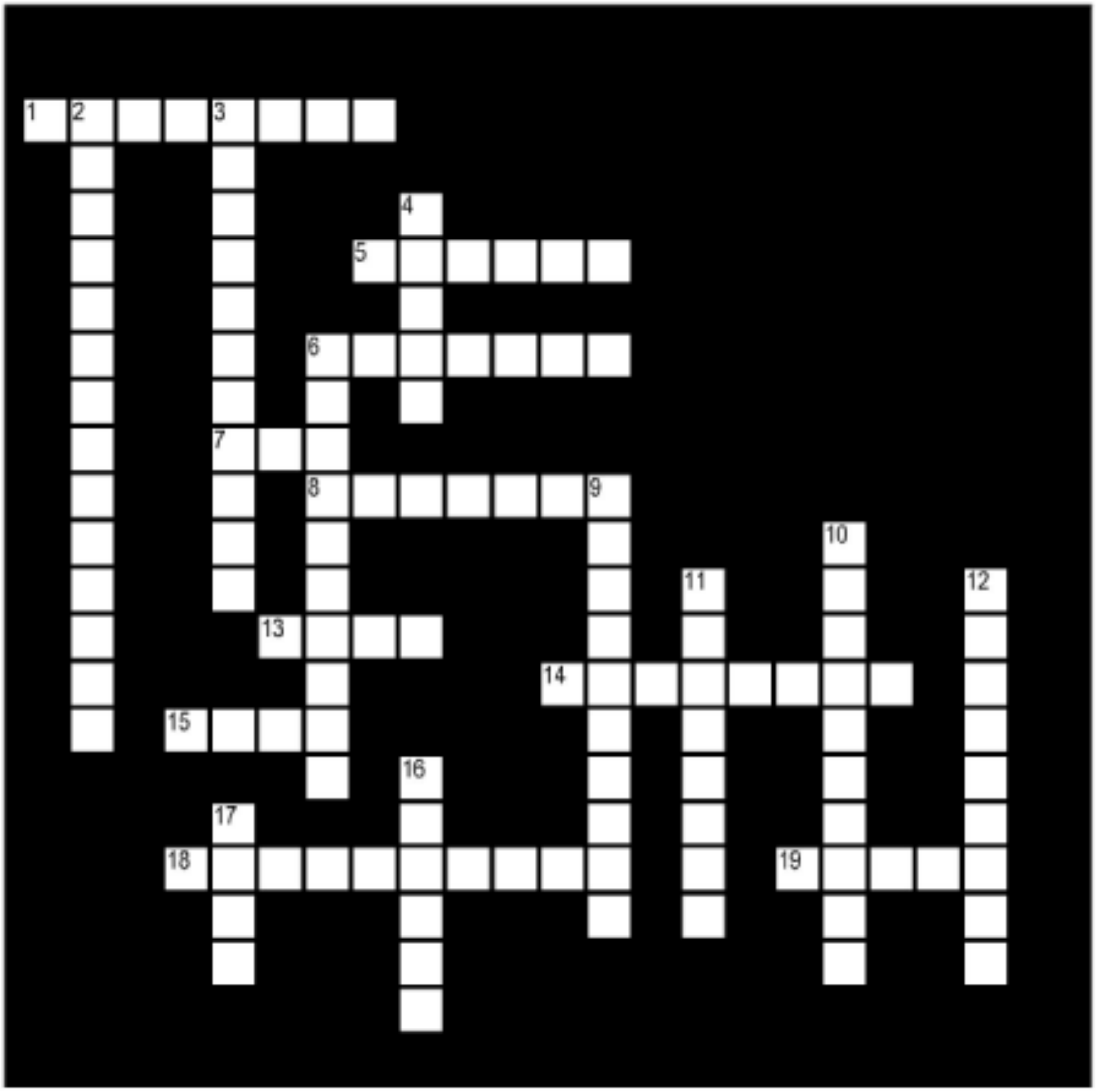
17. _______________kg (10 pts) The air mass that entered the chamber,

18. _______________kJ (10 pts) Work done by the air, and

19. _______________kJ (10 pts) Heat transfer (specify in/out of system).



(20) Crossword Puzzle



WRITE NEATLY. IF I CAN'T READ IT, IT'S NOT THERE.

ACROSS

1 is a device that increases the pressure of a fluid by decreasing the fluid velocity.

5 is a device that increases the velocity of a fluid at the expense of decreasing pressure.

6 mixing _______ is the section of a control volume where the mixing process takes place for two or more streams of fluids.

7 is a device that increases the pressure of a gas slightly (typical pressure ratios are less than 3) and is mainly used to mobilize a gas.

8 is a device that produces shaft work due to a decrease of enthalpy, kinetic, and potential energies of a flowing fluid.

13 is a device that increases the pressure of liquids very much as compressors increase the pressure of gases.

14 ____ ______ rate is the amount of mass flowing through a cross section per unit time.

15 is defined as the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference.

18 is a device that increases the pressure of a gas to very high pressures (typical pressure ratios are greater than 3).

19 ____ law of thermodynamics is simply a statement of the conservation of energy principle, and it asserts that total energy is a thermodynamic property.

DOWN

2 _______ substances such as liquids and solids, have densities that have negligible variation with pressure.

3 **UNIFORM FLOW** process involves the following idealization: The fluid flow at any inlet or exit is uniform and steady, and thus the fluid properties do not change with time or position over the cross section of an inlet or exit. If they do change with time, the fluid properties are averaged and treated as constants for the entire process.

4 _____ energy of a system is the sum of the numerous forms of energy that can exist within the system such as internal (sensible, latent, chemical, and nuclear), kinetic, potential, electrical, and magnetic.

6______ equation is the conservation of mass equation as it is often referred to in fluid mechanics.

9 heat ________ are devices where two moving fluid streams exchange heat without mixing.

10 ________ valves are any kind of flow-restricting devices that cause a significant pressure drop in a flowing fluid. Some familiar examples are ordinary adjustable valves, capillary tubes, and porous plugs.

11 ________-flow, or transient-flow processes, are processes that involve changes within a control volume with time.

12 in an ________ process there is no heat transfer.

16 means no change with time.

17 is the energy transfer associated with a force acting through a distance.

BONUS

A. (5 pts) Select one: A hurricane is best described as a (a)heat engine (b) refrigerator (c) heat pump. Explain.

B. (4 pts) The Celsius temperature scale is defined by the freezing and boiling points of pure water at sea level. What two phenomena define the Fahrenheit temperature scale?

C. (10 pts) Kim KW has summoned you to assess a dangerous situation: Kanye has put liquid nitrogen (LN2) into a bottle, sealed it, and is now running around with it. The nitrogen has begun to boil and everyone is rightfully worried that the bottle will explode, leveling the entire village. Your task is to save the day.

Here is what you learn from Quentin, a true blokey bloke from around the way:

- The LN2 was at atmospheric pressure (0.00125 m^3/kg) when it was poured into the bottle.
- That bottle and the air in it were at 7 °C when the LN2 was added. You can treat the air that's already in the bottle as nitrogen gas. You **do not** have to account for air that is displaced by the LN2.
- The bottle capacity is 500 mL and its burst pressure is 1 MPa.
- You **cannot** prevent the bottle and the LN2 inside from reaching 300 K.

What is the maximum volume of LN2 [mL] that could have been initially poured into the bottle and still avoid tragedy?

BY THE WAY, DON'T EVER DO THIS. IT'S A REALLY EFFECTIVE WAY TO LOSE YOUR FINGERS, YOUR EYES, YOUR FREEDOM, YOUR COOL, ETC.

TABLE A-17 **Properties of Saturated Propane (Liquid–Vapor): Pressure Table**

Pressure Conversions: 1 bar = 0.1 MPa = 10^2 kPa

Press. bar	Temp. °C	Specific Volume m^3/kg Sat. Liquid $v_f \times 10^3$	Specific Volume m^3/kg Sat. Vapor v_g	Internal Energy kJ/kg Sat. Liquid u_f	Internal Energy kJ/kg Sat. Vapor u_g	Enthalpy kJ/kg Sat. Liquid h_f	Enthalpy kJ/kg Evap. h_{fg}	Enthalpy kJ/kg Sat. Vapor h_g	Entropy kJ/kg · K Sat. Liquid s_f	Entropy kJ/kg · K Sat. Vapor s_g	Press. bar
0.05	–93.28	1.570	6.752	–114.6	326.0	–114.6	474.4	359.8	–0.556	2.081	0.05
0.10	–83.87	1.594	3.542	–95.1	335.4	–95.1	465.9	370.8	–0.450	2.011	0.10
0.25	–69.55	1.634	1.513	–64.9	350.0	–64.9	452.7	387.8	–0.297	1.927	0.25
0.50	–56.93	1.672	0.7962	–37.7	363.1	–37.6	440.5	402.9	–0.167	1.871	0.50
0.75	–48.68	1.698	0.5467	–19.6	371.8	–19.5	432.3	412.8	–0.085	1.841	0.75
1.00	–42.38	1.719	0.4185	–5.6	378.5	–5.4	425.7	420.3	–0.023	1.822	1.00
2.00	–25.43	1.781	0.2192	33.1	396.6	33.5	406.9	440.4	0.139	1.782	2.00
3.00	–14.16	1.826	0.1496	59.8	408.7	60.3	393.3	453.6	0.244	1.762	3.00
4.00	–5.46	1.865	0.1137	80.8	418.0	81.5	382.0	463.5	0.324	1.751	4.00
5.00	1.74	1.899	0.09172	98.6	425.7	99.5	372.1	471.6	0.389	1.743	5.00
6.00	7.93	1.931	0.07680	114.2	432.2	115.3	363.0	478.3	0.446	1.737	6.00
7.00	13.41	1.960	0.06598	128.2	438.0	129.6	354.6	484.2	0.495	1.733	7.00
8.00	18.33	1.989	0.05776	141.0	443.1	142.6	346.7	489.3	0.540	1.729	8.00
9.00	22.82	2.016	0.05129	152.9	447.6	154.7	339.1	493.8	0.580	1.726	9.00
10.00	26.95	2.043	0.04606	164.0	451.8	166.1	331.8	497.9	0.618	1.723	10.00
11.00	30.80	2.070	0.04174	174.5	455.6	176.8	324.7	501.5	0.652	1.721	11.00
12.00	34.39	2.096	0.03810	184.4	459.1	187.0	317.8	504.8	0.685	1.718	12.00
13.00	37.77	2.122	0.03499	193.9	462.2	196.7	311.0	507.7	0.716	1.716	13.00
14.00	40.97	2.148	0.03231	203.0	465.2	206.0	304.4	510.4	0.745	1.714	14.00
15.00	44.01	2.174	0.02997	211.7	467.9	215.0	297.9	512.9	0.772	1.712	15.00
16.00	46.89	2.200	0.02790	220.1	470.4	223.6	291.4	515.0	0.799	1.710	16.00
17.00	49.65	2.227	0.02606	228.3	472.7	232.0	285.0	517.0	0.824	1.707	17.00
18.00	52.30	2.253	0.02441	236.2	474.9	240.2	278.6	518.8	0.849	1.705	18.00
19.00	54.83	2.280	0.02292	243.8	476.9	248.2	272.2	520.4	0.873	1.703	19.00
20.00	57.27	2.308	0.02157	251.3	478.7	255.9	265.9	521.8	0.896	1.700	20.00
22.00	61.90	2.364	0.01921	265.8	481.7	271.0	253.0	524.0	0.939	1.695	22.00
24.00	66.21	2.424	0.01721	279.7	484.3	285.5	240.1	525.6	0.981	1.688	24.00
26.00	70.27	2.487	0.01549	293.1	486.2	299.6	226.9	526.5	1.021	1.681	26.00
28.00	74.10	2.555	0.01398	306.2	487.5	313.4	213.2	526.6	1.060	1.673	28.00
30.00	77.72	2.630	0.01263	319.2	488.1	327.1	198.9	526.0	1.097	1.664	30.00
35.00	86.01	2.862	0.009771	351.4	486.3	361.4	159.1	520.5	1.190	1.633	35.00
40.00	93.38	3.279	0.007151	387.9	474.7	401.0	102.3	503.3	1.295	1.574	40.00
42.48	96.70	4.535	0.004535	434.9	434.9	454.2	0.0	454.2	1.437	1.437	42.48

v_f = (table value)/1000

Propane

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

TABLE A-18 Properties of Superheated Propane Vapor (*Continued*)

T °C	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K
	p = 10.0 bar = 1.0 MPa (T_{sat} = 26.95°C)				*p* = 12.0 bar = 1.2 MPa (T_{sat} = 34.39°C)			
Sat.	0.04606	451.8	497.9	1.723	0.03810	459.1	504.8	1.718
30	0.04696	457.1	504.1	1.744				
40	0.04980	474.8	524.6	1.810	0.03957	469.4	516.9	1.757
50	0.05248	492.4	544.9	1.874	0.04204	487.8	538.2	1.824
60	0.05505	510.2	565.2	1.936	0.04436	506.1	559.3	1.889
70	0.05752	528.2	585.7	1.997	0.04657	524.4	580.3	1.951
80	0.05992	546.4	606.3	2.056	0.04869	543.1	601.5	2.012
90	0.06226	564.9	627.2	2.114	0.05075	561.8	622.7	2.071
100	0.06456	583.7	648.3	2.172	0.05275	580.9	644.2	2.129
110	0.06681	603.0	669.8	2.228	0.05470	600.4	666.0	2.187
120	0.06903	622.6	691.6	2.284	0.05662	620.1	688.0	2.244
130	0.07122	642.5	713.7	2.340	0.05851	640.1	710.3	2.300
140	0.07338	662.8	736.2	2.395	0.06037	660.6	733.0	2.355
	p = 14.0 bar = 1.4 MPa (T_{sat} = 40.97°C)				*p* = 16.0 bar = 1.6 MPa (T_{sat} = 46.89°C)			
Sat.	0.03231	465.2	510.4	1.714	0.02790	470.4	515.0	1.710
50	0.03446	482.6	530.8	1.778	0.02861	476.7	522.5	1.733
60	0.03664	501.6	552.9	1.845	0.03075	496.6	545.8	1.804
70	0.03869	520.4	574.6	1.909	0.03270	516.2	568.5	1.871
80	0.04063	539.4	596.3	1.972	0.03453	535.7	590.9	1.935
90	0.04249	558.6	618.1	2.033	0.03626	555.2	613.2	1.997
100	0.04429	577.9	639.9	2.092	0.03792	574.8	635.5	2.058
110	0.04604	597.5	662.0	2.150	0.03952	594.7	657.9	2.117
120	0.04774	617.5	684.3	2.208	0.04107	614.8	680.5	2.176
130	0.04942	637.7	706.9	2.265	0.04259	635.3	703.4	2.233
140	0.05106	658.3	729.8	2.321	0.04407	656.0	726.5	2.290
150	0.05268	679.2	753.0	2.376	0.04553	677.1	749.9	2.346
160	0.05428	700.5	776.5	2.431	0.04696	698.5	773.6	2.401
	p = 18.0 bar = 1.8 MPa (T_{sat} = 52.30°C)				*p* = 20.0 bar = 2.0 MPa (T_{sat} = 57.27°C)			
Sat.	0.02441	474.9	518.8	1.705	0.02157	478.7	521.8	1.700
60	0.02606	491.1	538.0	1.763	0.02216	484.8	529.1	1.722
70	0.02798	511.4	561.8	1.834	0.02412	506.3	554.5	1.797
80	0.02974	531.6	585.1	1.901	0.02585	527.1	578.8	1.867
90	0.03138	551.5	608.0	1.965	0.02744	547.6	602.5	1.933
100	0.03293	571.5	630.8	2.027	0.02892	568.1	625.9	1.997
110	0.03443	591.7	653.7	2.087	0.03033	588.5	649.2	2.059
120	0.03586	612.1	676.6	2.146	0.03169	609.2	672.6	2.119
130	0.03726	632.7	699.8	2.204	0.03299	630.0	696.0	2.178
140	0.03863	653.6	723.1	2.262	0.03426	651.2	719.7	2.236
150	0.03996	674.8	746.7	2.318	0.03550	672.5	743.5	2.293
160	0.04127	696.3	770.6	2.374	0.03671	694.2	767.6	2.349
170	0.04256	718.2	794.8	2.429	0.03790	716.2	792.0	2.404
180	0.04383	740.4	819.3	2.484	0.03907	738.5	816.6	2.459

Propane

TABLE A-3 **Properties of Saturated Water (Liquid–Vapor): Pressure Table**

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949	0.90
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594	1.00
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959	4.00
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212	5.00
6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600	6.00
7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00
8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628	8.00
9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226	9.00
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448	15.0
20.0	212.4	1.1767	0.09963	906.44	2600.3	908.79	1890.7	2799.5	2.4474	6.3409	20.0
25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1841.0	2803.1	2.5547	6.2575	25.0
30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1795.7	2804.2	2.6457	6.1869	30.0
35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1753.7	2803.4	2.7253	6.1253	35.0
40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7964	6.0701	40.0
45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199	45.0
50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734	50.0
60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892	60.0
70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2772.1	3.1211	5.8133	70.0
80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2758.0	3.2068	5.7432	80.0
90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2742.1	3.2858	5.6772	90.0
100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3596	5.6141	100.
110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2705.6	3.4295	5.5527	110.

v_f = (table value)/1000

H_2O

TABLE A-22 **Ideal Gas Properties of Air**

T(K), h and u (kJ/kg), $s°$ (kJ/kg · K)											
				when $\Delta s = 0$[1]						when $\Delta s = 0$	
T	h	u	$s°$	p_r	v_r	T	h	u	$s°$	p_r	v_r
200	199.97	142.56	1.29559	0.3363	1707.	450	451.80	322.62	2.11161	5.775	223.6
210	209.97	149.69	1.34444	0.3987	1512.	460	462.02	329.97	2.13407	6.245	211.4
220	219.97	156.82	1.39105	0.4690	1346.	470	472.24	337.32	2.15604	6.742	200.1
230	230.02	164.00	1.43557	0.5477	1205.	480	482.49	344.70	2.17760	7.268	189.5
240	240.02	171.13	1.47824	0.6355	1084.	490	492.74	352.08	2.19876	7.824	179.7
250	250.05	178.28	1.51917	0.7329	979.	500	503.02	359.49	2.21952	8.411	170.6
260	260.09	185.45	1.55848	0.8405	887.8	510	513.32	366.92	2.23993	9.031	162.1
270	270.11	192.60	1.59634	0.9590	808.0	520	523.63	374.36	2.25997	9.684	154.1
280	280.13	199.75	1.63279	1.0889	738.0	530	533.98	381.84	2.27967	10.37	146.7
285	285.14	203.33	1.65055	1.1584	706.1	540	544.35	389.34	2.29906	11.10	139.7
290	290.16	206.91	1.66802	1.2311	676.1	550	554.74	396.86	2.31809	11.86	133.1
295	295.17	210.49	1.68515	1.3068	647.9	560	565.17	404.42	2.33685	12.66	127.0
300	300.19	214.07	1.70203	1.3860	621.2	570	575.59	411.97	2.35531	13.50	121.2
305	305.22	217.67	1.71865	1.4686	596.0	580	586.04	419.55	2.37348	14.38	115.7
310	310.24	221.25	1.73498	1.5546	572.3	590	596.52	427.15	2.39140	15.31	110.6
315	315.27	224.85	1.75106	1.6442	549.8	600	607.02	434.78	2.40902	16.28	105.8
320	320.29	228.42	1.76690	1.7375	528.6	610	617.53	442.42	2.42644	17.30	101.2
325	325.31	232.02	1.78249	1.8345	508.4	620	628.07	450.09	2.44356	18.36	96.92
330	330.34	235.61	1.79783	1.9352	489.4	630	638.63	457.78	2.46048	19.84	92.84
340	340.42	242.82	1.82790	2.149	454.1	640	649.22	465.50	2.47716	20.64	88.99
350	350.49	250.02	1.85708	2.379	422.2	650	659.84	473.25	2.49364	21.86	85.34
360	360.58	257.24	1.88543	2.626	393.4	660	670.47	481.01	2.50985	23.13	81.89
370	370.67	264.46	1.91313	2.892	367.2	670	681.14	488.81	2.52589	24.46	78.61
380	380.77	271.69	1.94001	3.176	343.4	680	691.82	496.62	2.54175	25.85	75.50
390	390.88	278.93	1.96633	3.481	321.5	690	702.52	504.45	2.55731	27.29	72.56
400	400.98	286.16	1.99194	3.806	301.6	700	713.27	512.33	2.57277	28.80	69.76
410	411.12	293.43	2.01699	4.153	283.3	710	724.04	520.23	2.58810	30.38	67.07
420	421.26	300.69	2.04142	4.522	266.6	720	734.82	528.14	2.60319	32.02	64.53
430	431.43	307.99	2.06533	4.915	251.1	730	745.62	536.07	2.61803	33.72	62.13
440	441.61	315.30	2.08870	5.332	236.8	740	756.44	544.02	2.63280	35.50	59.82

1. p_r and v_r data for use with Eqs. 6.41 and 6.42, respectively.

Useful Relationships

$$E_{in} - E_{out} = \Delta E_{system}$$

$$\dot{E}_{in} - \dot{E}_{out} = \frac{d}{dt} E_{system}$$

$$m_{in} - m_{out} = \Delta m_{system}$$

$$\dot{m}_{in} - \dot{m}_{out} = \frac{d}{dt} m_{system}$$

$$\dot{m} = \rho \vec{V} A$$

$$w_{b,out} = \int P\, dv$$

$$x \equiv \frac{m_g}{m}$$

$$x = \frac{v - v_f}{v_g - v_f} = \frac{u - u_f}{u_g - u_f} = \frac{h - h_f}{h_g - h_f} = \frac{s - s_f}{s_g - s_f}$$

$$h = u + Pv$$

$$h \approx h_{f@T} + v_{f@T}\left(P - P_{sat@T}\right)$$

$$\Delta P = \rho g \Delta z$$

$$\eta_{th} \equiv \frac{\text{desired output}}{\text{required input}}$$

$$\text{COP} \equiv \frac{\text{desired output}}{\text{required input}}$$

$$\left(\frac{Q_L}{Q_H}\right)_{\text{rev}} = \frac{T_L}{T_H}$$

$$PV = mRT = N\bar{R}T$$

$$\bar{\text{R}} = \begin{cases} 8.314\ \dfrac{\text{kJ}}{\text{kmol}\cdot\text{K}} \\ 1545\ \dfrac{\text{ft}\cdot\text{lbf}}{\text{lbmol}\cdot{}^\circ\text{R}} \\ 1.986\ \dfrac{\text{BTU}}{\text{lbmol}\cdot{}^\circ\text{R}} \end{cases}$$

$$F = ma$$

$$1\ \text{N} = (1\ \text{kg})\left(1\ \text{m/s}^2\right)$$

$$1\ \text{lbf} = (1\ \text{lbm})\,(1\ \text{g})$$

$$1\ \text{lbf} = (1\ \text{lbm})\left(32.174\ \text{ft/s}^2\right)$$

$$1\ \text{lbf} = (1\ \text{slug})\left(1\ \text{ft/s}^2\right)$$

Useful Conversions

Mass and Density

1 kg = 2.2046 lb
1 $g/cm^3 = 10^3\ kg/m^3$
1 $g/cm^3 = 62.428\ lb/ft^3$
1 lb = 0.4536 kg
1 $lb/ft^3 = 0.016018\ g/cm^3$
1 $lb/ft^3 = 16.018\ kg/m^3$

Length

1 cm = 0.3937 in
1 m = 3.2808 ft
1 in = 2.54 cm
1 ft = 0.3048 m

Velocity

1 km/h = 0.62137 mile/h
1 mile/h = 1.6093 km/h

Volume

1 $cm^3 = 0.061024\ in^3$
1 $m^3 = 35.315\ ft^3$
1 m^3 = 1000 liters
1 L = $10^{-3}\ m^3$
1 L = $0.0353\ ft^3$
1 $in^3 = 16.387\ cm^3$
1 $ft^3 = 0.028317\ m^3$
1 gal = $0.13368\ ft^3$
1 gal = $3.7854 \times 10^{-3}\ m^3$

Force

1 N = 1 $kg \cdot m/s^2$
1 N = 0.22481 lbf
1 lbf = 32.174 $lb \cdot ft/s^2$
1 lbf = 4.4482 N

Pressure

1 Pa = 1 N/m^2
1 bar = $10^5\ N/m^2$
1 bar = 100 kPa
1 Pa = $1.4504 \times 10^{-4}\ lbf/in^2$
1 atm = 1.01325 bar
1 atm = 14.696 lbf/in^2
1 lbf/in^2 = 6894.8 Pa
1 lbf/in^2 = 144 lbf/ft^2

Energy and Specific Energy

1 kWh = 3.6 MJ
1 J = 1 N·m = 0.73756 ft·lbf
1 kJ = 737.56 ft·lbf
1 kJ = 0.9478 Btu
1 kJ/kg = 0.42992 Btu/lb
1 ft·lbf = 1.35582 J
1 Btu = 778.17 ft·lbf
1 Btu = 1.0551 kJ
1 Btu/lb = 2.326 kJ/kg
1 kcal = 4.1868 kJ

Energy Transfer Rate

1 W = 1 J/s = 3.413 Btu/h
1 kW = 1.341 hp
1 Btu/h = 0.293 W
1 hp = 2545 Btu/h
1 hp = 550 ft·lbf/s
1 hp = 0.7457 kW

Specific Heat

1 kJ/kg·K = 0.238846 Btu/lb·°R
1 kcal/kg·K = 1 Btu/lb·°R
1 Btu/lb·°R = 4.1868 kJ/kg·K

Others

1 ton of refrigeration = 200 Btu/min
1 ton of refrigeration = 211 kJ/min
1 volt = 1 watt/ampere

Standard Acceleration of Gravity

g = 9.80665 m/s^2
g = 32.174 ft/s^2

Standard Atmospheric Pressure

1 atm = 1.01325 bar
1 atm = 14.696 lbf/in^2
1 atm = 760 mmHg = 29.92 inHg

Temperature Relations

T(°R) = 1.8 T(K)
T(°C) = T(K) − 273.15
T(°F) = T(°R) − 459.67